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14. ABSTRACT
These articles describe an investigation by the Aircrew Training Division of Armstrong Laboratory into the Specialized Undergraduate Pilot Training (SUPT) regarding application of advanced modeling and simulation technologies. The first article describes the results of pilot training study and several technologies and training methods that were recommended for SUPT. The second article provides a rationale for implementing modeling and simulation technologies and training methods based on a review of research on learning and instruction.

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Modeling and Simulation Technologies:
Two Articles from Air Force Research

The following two articles summarize the results of a comprehensive study of pilot training and training technologies by the Aircrew Training Research Division of Armstrong Laboratory (AL/HRA). The focus of this study was on Specialized Undergraduate Pilot Training (SUPT) conducted by the U. S. Air Force, Air Education and Training Command.

The study involved several major tasks: (1) a review and analyses of Air Force training programs, modernization plans, training policies, and practices; (2) a review of learning, education, and training research; (3) analyses of survey responses and structured interviews with Air Force fighter pilots, instructor pilots, squadron leaders, and SUPT management; (4) an examination of pilot instructor training curriculum, instructor techniques manuals, and SUPT course syllabi; and (5) a revision of study conclusions based on consultation with pilots, engineers, and behavioral scientists.

The first article is a condensed version of the final technical report, **Potential modeling and simulation contributions to Air Education and Training Command flying training: Specialized Undergraduate Pilot Training** *(AL/HR–TR–1995–0157), Andrews* **et al.** *(1995). It describes the results of the pilot training study and several technologies and training methods that were recommended for SUPT.*

The second article is a condensed version of the final technical report, **Reasons for implementing modeling and simulation technologies in Specialized Undergraduate Pilot Training** *(Report No. AL/HR–TR–1995–0078), Mattoon (1995). This article provides a rationale for implementing modeling and simulation technologies and training methods based on a review of research on learning and instruction.*

The purpose of these two articles, prepared especially for this magazine, is to inform our readers of existing and emerging training technologies, stimulate ideas on how technology may be employed to improve instructional effectiveness and efficiency, and generalize results of the pilot training study to other education and training environments, such as public schools, colleges, and technical training programs.

References

Andrews, D. H., Edwards, B. J., Mattoon, J. S., Thurman, R. A., Shinn, D., Carroll, L. A., Moor, W. C., & Nelson, B. G. (1995). **Potential modeling and simulation contributions to Air Education and Training Command flying training: Specialized Undergraduate Pilot Training** *(Report No. AL/HR–TR–1995–0157). Armstrong Laboratory, Aircrew Training Research Division, Mesa, AZ.*

Mattoon, J. S. (1995). **Reasons for implementing modeling and simulation technologies in Specialized Undergraduate Pilot Training** *(Report No. AL/HR–TR–1995–0078). AL/HRA, Mesa, AZ.*

The Cover (courtesy of Brian Watkins, Imaging/Multimedia Specialist, Hughes Training, Inc.): The student pilot shown on the cover of this issue is wearing a head-mounted display (HMD) that provides a 360-degree field of view, which enables the pilot-in-training to see simulated views of ground terrain and other aircraft that are in visual range. The aircraft shown at the left (see cover) of the simulator cockpit shows a portion of the imagery that the trainee would be able to see through the HMD.

Potential Modeling and Simulation Contributions to Specialized Undergraduate Pilot Training

Dee H. Andrews
Bernell J. Edwards
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The Air Education and Training Command of the U. S. Air Force recently called for an analysis and evaluation of its flying training programs, with a view toward training technology modernization. The Aircrew Training Division of Armstrong Laboratory was selected to conduct a study to identify current and future training problems and challenges that could be met by the infusion of advanced modeling and simulation (M&S) technologies (Andrews *et al.*, 1995). Although pilot training is a fairly unique environment, the knowledge and skills required of pilots are similar to those in many technical vocations, especially for jobs that deal with potentially dangerous equipment, require fast decision making, and involve the operation and monitoring of complex electronic systems. Such occupations are common in modern manufacturing plants, heavy industry (e.g., steel and lumber mills), and power generation facilities (e.g., nuclear and hydroelectric power plants). Thus, we believe that our work may be of some use to the general readership of this magazine.

Rapid advances in modeling and simulation in the past few years have brought about affordable and effective M&S tools for Air Force Training applications (Gray & Edwards, 1991). In many respects, the training concepts elaborated in this article are not new. Some have been recognized as desirable solutions for some time (Fowell, Rawlinson, Hirsch, & Hesse, 1971), but technology has been lacking to enable many of the suggested technology implementations. Now, however, newly emerging M&S hardware and software may open the way for far-sighted and even revolutionary training concepts to become a reality. The authors of the present article believe that M&S applications will increase significantly as training enhancements. These tools will be applied not only to increase the impact of artificial environments on skill acquisition but also to improve the dynamics of the instructional process.

The authors are with the U.S. Air Force's Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division, Mesa, Arizona.

Challenges to Undergraduate Pilot Training and Potential M&S Solutions

A research team, consisting of psychologists and engineers, was formed to evaluate the current Specialized Undergraduate Pilot Training (SUPT) program. The major objectives of the study were to reveal problem areas (challenges) of pilot training and formulate potential M&S-based solutions to improve training effectiveness and efficiency. Team members consulted a variety of experts, including operations experts, instructor pilots (IPs), and training managers.

The investigation followed a needs assessment model recommended by Kaufman (1991). Investigators developed a questionnaire in consultation with subject matter experts. The questionnaire was designed to draw information from authoritative sources concerning the challenges and problems of training within SUPT. The 64th Operational Support Squadron at Reese Air Force Base was selected for data collection. Investigators conducted structured interviews with 28 IPs. Pilots were asked to identify and define specific problems and difficulties experienced in teaching student pilots, student learning problems, their perceptions of the training program, training resources, management, student motivation, and related issues. Answers given by IPs were recorded on cassette tapes and on questionnaire forms by interviewers for later tabulation and analysis. Findings from the interviews were correlated with SUPT training objectives and course syllabi.

Following the analysis, a summary of the findings and a proposed set of M&S-based solutions were presented to IPs to verify the team's interpretation of the major training challenges and to provide feedback on the proposed solutions. This procedure worked smoothly to identify and clearly define real problems and challenge areas within the pilot training environment.

The user-oriented approach should be considered for evaluating training in any complex environment where various levels of administration and operations lead to a variety of users' conceptual models of program goals and objectives (Landauer, 1995; Mattoon, 1992). A synthesis of results from the structured interviews and

consultation with many levels of SUPT provided a more comprehensive view of student and instructor pilot needs as well as estimates of feasibility for Air Force procurement of the proposed training systems.

Descriptions of Training Challenges

Six training challenges within SUPT were identified and validated. A brief description of each is presented below.

1. Position Interpretation

This fundamental skill enables students to know where they are at any point during flight. IPs say it is one of the most difficult skills for students to learn. Students have trouble translating two-dimensional information from navigation instruments into three-dimensional flight geometry. Part of the difficulty arises from the design of navigation systems on the primary training aircraft, the T–37. The student must interpret and correlate information from four different cockpit instruments. Learning difficulties are further compounded by the multiplicity of tasks which occupy the pilot's attention during flight. Similar difficulties exist in non-military systems operator environments whereby many dynamic displays are intended to keep the operator(s) informed of the state of a system that is spatially distributed over a broad area (e.g., control room of a large power plant or control station in a manufacturing plant).

2. Fix-to-Fix Navigation

Navigating from point A to point B (from a very short distance to many miles at various altitudes) is another fundamental piloting skill that students must develop during the SUPT training cycle. Like position interpretation, it is a three-dimensional (3D) computational and visualization problem that is difficult to learn using information obtained from two-dimensional (2D) cockpit displays. For maximum safety, students need substantial practice integrating the perceptual and cognitive aspects in ground-based training activities before attempting this task in the aircraft. Students are often encouraged to practice these skills mentally, but it is difficult to do so without being able to meaningfully visualize the implications of complex instrument readings. The current program lacks training devices that would provide dynamic practice, assess level of skill, and provide instructional feedback on the fix-to-fix navigation task. Navigation tasks in seagoing vessels and over unmarked land terrain also require some challenging technical skills.

3. Overhead Landing Pattern

This task is one of the most difficult for students to master, because it requires the student pilot to perform a number of integrated tasks, some simultaneously and others in rapid succession, to safely land the aircraft. Ground-based practice plays an important role in introducing the task, but the current flight simulators do not provide the visual capabilities needed to support practicing overhead landing patterns. That is, for a flight simulator to provide adequate landing practice, it must reproduce the same out-of-the-cockpit views experienced during a landing. Such a visual system needs to be combined with a fully-functional cockpit simulator to enable the student to incorporate display-interpretation skills, aircraft control skills, and knowledge of how to use perceptual cues during the landing. The operational flight trainer (OFT) that is currently used in SUPT is not equipped with a visual system that can provide students with a view of key ground culture (e.g., buildings, roads, etc.) during simulated flight. Also, as exhibited by many early flight simulator designs (Andrews, 1988), the OFT does not provide the type of guided practice needed to maximize students' speed and accuracy for performing complex cockpit procedures.

4. Formation Flight

Learning to maneuver an aircraft in close proximity to other aircraft involves development of precise hand-eye coordination skills. Pilots rely on specific visual cues to judge distance and closure with other aircraft (e.g., wing tips, running lights, and even rivet patterns). Most of these skills are developed in the aircraft due to the limited capacity of ground-based training systems to simulate such phenomena. OFTs lack sufficient visual display capabilities and cannot be networked to enable two or more pilots to practice formation flight maneuvers. This results in the consumption of large amounts of jet fuel and instructor time while students accrue sufficient practice in the aircraft to master the task.

5. Low Altitude Flight

Like formation flight, low altitude flying requires precise aircraft control. It requires the ability to recognize critical visual information quickly and accurately. It also requires the pilot to divide his/her attention among different types of tasks and decisions in time-constrained situations. These include managing the aircraft, performing a variety of mission-related tasks, and maintaining safe minimum altitudes. Current limitations in training for this task stem from the lack of automated training devices that jointly build students' knowledge and task-execution skills. Training devices currently used in SUPT academics and simulator training are not efficient in reproducing such time-constrained task environments nor developing visual discrimination skills needed for safe low-altitude flight.

6. Instructor Continuation Training

All IPs assigned to SUPT undergo an eight-week

instructor pilot course. During this course IPs receive some training on how to instruct students. But, due to the brief span of the course, only a cursory treatment of these principles is provided. IPs get little training on specific methods for diagnosing student learning problems and conducting effective one-to-one coaching. During interviews conducted for the present study, we observed that IPs tended to describe student learning problems in terms of the inability to perform flying tasks, rather than in terms of learning or instructional processes. Apparently, IPs are deficient in such skills. Thus, continuation training that provides more explicit strategies and tactics for dealing with student learning problems was recommended. This problem is also apparent in higher education environments where college professors have obtained their Ph.D. and are quite competent in their field but often experience severe difficulty and frustration in teaching undergraduate students, because the professors have little or no training in applied teaching strategies.

Descriptions of Technology Solutions

Each technology solution proposed for modernization of SUPT is briefly described below. Additionally, a proof-of-concept videotape was developed as a supplement to this article (Mattoon & Gagel, 1995) and was presented to upper management within Air Education and Training Command to graphically demonstrate how each technology may enhance pilot training.

1. SUPT Hub Computer System

This centralized database system integrates most of the proposed technology solutions for SUPT modernization. It would contain and manage simulation software, learning library resources, and student proficiency profiles—ongoing records that summarize each student's training progress, performance on required tasks, and specific pilot capabilities. Training software (e.g., computer-assisted instruction programs and interactive training simulations) and proficiency profiles will be accessible to students and IPs via personal computer systems and other training hardware interfaces. The SUPT hub would distribute electronic training-support to classrooms, simulation training sites, and even to the cockpit of the training aircraft via a local area network (LAN) system and portable electronic trainers (PETs) (described below). It would consist of a "super minicomputer" with high storage and processing capacity—for real-time student performance analysis during dynamic training activities—and advanced graphic capabilities for organizing and distributing graphic databases that serve multimedia and high-fidelity flight simulators throughout the training base.

Figure 1 shows the communication links among PETs, training sites throughout the training base, and the SUPT hub. Such an integrated infrastructure offers some unique capabilities to any large training environment: immediate communication and data transfer among students, instructors, and training sites; opportunities for simultaneous distributed training to all connected sites and field locations; and the ability to engage students in joint training activities (cooperative learning) exercises.

2. Specialized Visual Displays

Large visual displays are electronic devices for projecting and displaying computer-generated imagery, digitized photography and video, text, diagrams, and maps. The advantage of such displays over print and videotape media, when used in conjunction with computers, is that they support active learning processes instead of passive information viewing engendered by videotape and other sequential media presentations. Also, pilot training curriculum consists of many aerodynamic principles, dynamic aircraft systems, and flying maneuvers that must be seen, and later, accurately visualized by the student pilot to fully understand. Large, high-quality displays are now affordable for many types of training operations, and the long-term technical forecast is favorable for continuing cost-to-capability improvement. The reduced cost of these systems will soon enable trainers to reap the benefits of visual information which have previously been too expensive to be practical in schools and training programs.

Providing depth cues and volumetric graphic capabilities to simulation displays can greatly enhance viewer's ability to perceive distance and spatial relationships. Several interface technologies use different approaches to simulate 3D vision within computer-generated simulations. For example, some displays project imagery on flat display surfaces that are viewed from a distance, while head-mounted displays (HMDs) provide separate views that are projected to each eye and overlapped to produce 3D images. Such displays are useful in a variety of training phases where it is important for students to gain an understanding of 3D flight dynamics. Similarly, high school and college students must be able to visualize certain types of physical principles, such as atomic or molecular structures, to fully grasp advanced scientific concepts. Large visual displays that provide perspective views of complex objects and allow the viewpoint to be altered in real-time could accelerate students' grasp of many types of dynamic phenomena.

Generally speaking, an HMD is connected to a computer-based image generator system that projects two images, one to each eye at a slightly different viewpoint, via miniature liquid crystal displays (LCDs)

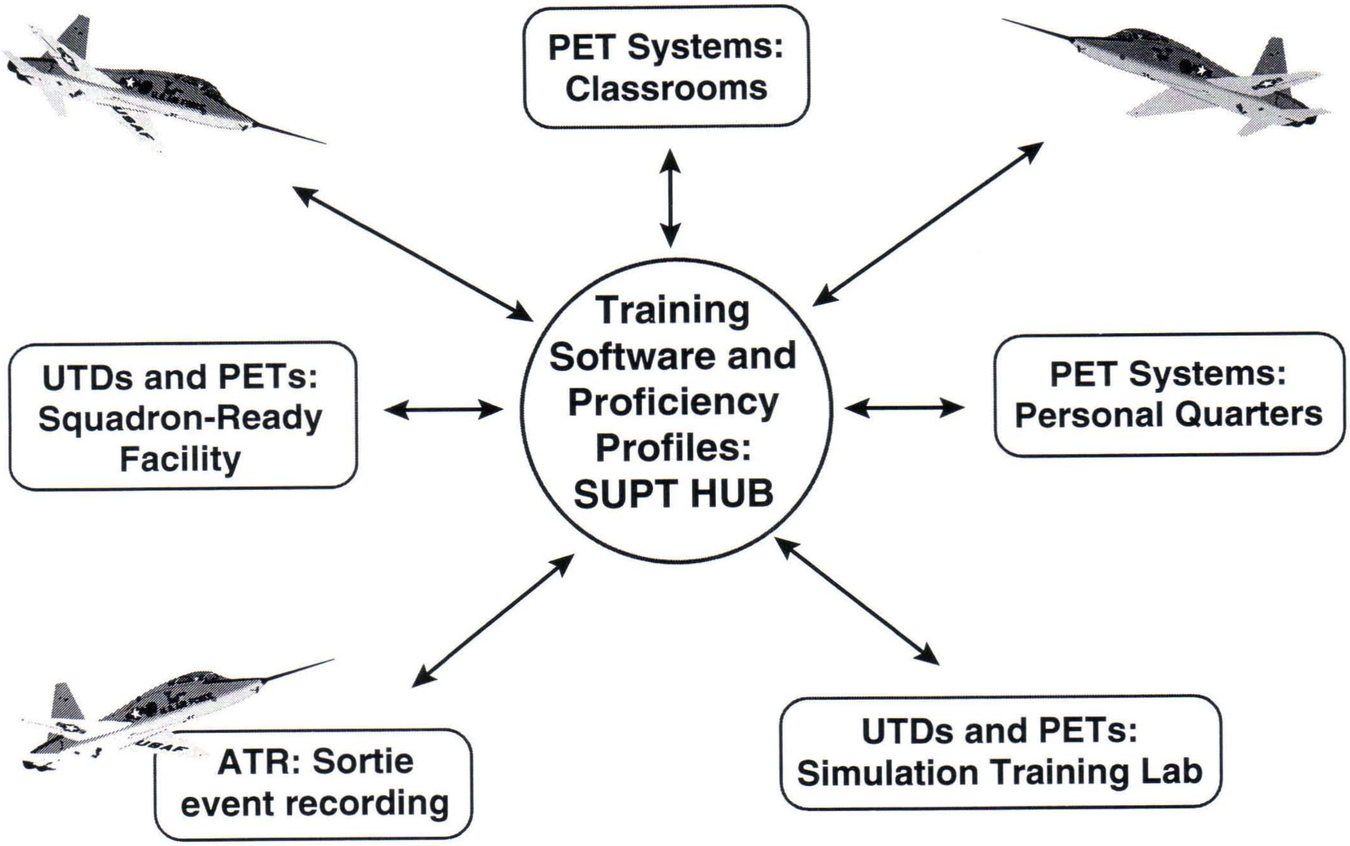

Figure 1. An integrated infrastructure of communication links.

or cathode ray tubes (CRTs). This process simulates human binocular vision so that the viewer is able to perceive volumetric objects as if they were physical entities in real space (Ellis, Kaiser, & Granwald, 1993). The viewer is visually "partitioned" from his/her physical surroundings and "immersed" within the simulated scene. The resulting experience, combined with the technology that makes it possible, is referred to as "virtual reality" (Thurman & Mattoon, 1994). The training capabilities of virtual reality systems are expected to increase rapidly with the advancement of better and lower-cost HMDs in the near future (Boman & Piantanida, 1993).

A position tracking system enables an HMD user to move his or her line of site and head position while the simulated imagery changes to accommodate the shift in the viewer's perspective. As the viewer's head turns, the available field of view shifts accordingly. HMDs can also be designed so that the computer tracks eye position and changes the simulated environment relative to the viewer's eye movements. The overall capability of HMD and position-tracking technology is that a student pilot can step into a flight simulator cockpit, don an HMD, and be "transported" into an artificial, but very realistic, flight environment where virtually all types of flying tasks and maneuvers can be performed as they would be in the actual aircraft. The student would be able to look down and view the local ground culture at various altitudes and also see other aircraft that are within visual range.

HMDs may enhance the effectiveness of training students to fly overhead landing patterns and formation maneuvers. When used outside of a cockpit simulator, the HMD could provide views of flight maneuvers from a variety of perspectives and enable students to gain an understanding of flight situations before attempting tasks in the simulator or the aircraft. Although current HMDs consist of fairly large and somewhat cumbersome head gear, future versions are expected to take the form of simple visors that are not much larger

or heavier than ski goggles. The wide-ranging possibilities for using HMDs for education and training is limited only by the number of concepts and tasks that must be viewed in a 3D format to be studied, understood, and learned, and those that are unavailable (e.g., microscopic objects and theoretical structures) or too rare or too dangerous (e.g., earthquakes and volcanic activity) to be viewed in real-life situations.

The Display for Advanced Research and Training (DART) is a geometric configuration of several rear-screen projected displays that provides out-the-window visual imagery for flight simulators. It is designed to complement a variety of simulation cockpit configurations, including the unit training device (UTD) flight simulator. DART was developed to provide high-quality visual display characteristics at a low cost. Instead of immersing the viewer within an artificial (virtual) environment, DART surrounds the UTD cockpit with a set of interlocking displays that form a dome structure. This produces a similar effect to immersing the viewer in the imagery via an HMD but does not block out the user's view of the surrounding physical space.

The rear-screen projectors in the DART system exceed 1000 lines of video resolution. Resolution to the pilot's eye is 4.75 arcminutes/pixel, and the field of regard is about 300 degrees horizontally and 150 degrees vertically. A Polhemus magnetic tracker is used to track the pilot's head movement, and resulting data are used to reduce image generator (IG) channel processing requirements by dimming the projectors for imagery that is out of the pilot's view. Most of the display components are commercially available, and some are quite inexpensive in comparison to most specialized display systems. The overall result is high fidelity "wraparound" visual imagery, in full color, that provides full visual flight simulation capabilities at a low cost. The Mini-DART, a newer version of the original DART system, uses fewer IG channels and display screens to accomplish almost the same capability as the full-size DART but occupies a much smaller space, has greater portability, and is more economical. DART offers advanced flight training capabilities similar to those of the HMD but provides higher fidelity imagery than low-cost HMDs and does not interfere with the student pilot's view of cockpit controls.

Because of the portability and small size of HMDs, future flight trainers will likely be equipped with low-cost visor-type HMDs instead of surrounding display systems like the DART. However, where there is a need for viewers to move in and out of a display area and be surrounded by a simulated space, the DART may be a very practical solution. For example, one could envision a viewing room equipped with a full DART dome that is able to surround a small group of students or museum patrons for the purpose of visually teaching or demonstrating various theoretical or physical phenomena. Figure 2 shows an artist's conception of the UTD flight simulator equipped with each of the two proposed visual display systems, the Mini-DART on the left and a light-weight visor on the right.

3. Upgrades in Computer-Assisted Instruction (CAI) and Portable Electronic Trainers (PETs)

Recent developments in microprocessors, application software, computer architecture, and multimedia technology have resulted in tools that offer great potential for improving the capability of CAI and simulation-based training. It is likely that instructors and students would benefit from a microcomputer-based portable electronic trainer (PET) that would provide each individual with advanced training-support and communications capabilities at any location on the training base. The PET would be small enough to fit into a flight suit pocket, yet would provide the student with immediate access to his/her student profile and communication with any instructor pilot. The PET would operate independently via a cellular modem to enable students and instructors to access student profiles, certain types of CAI, and other pilot training-support software (e.g., aircraft scheduling and flight planning programs) at any location on the training base. The PET would also dock with a desktop training station that would provide all the computer and display power needed for individualized training (e.g., keyboard, mouse, specialized visual displays, CD ROM) in the classroom or at strategically located sites on the training base (e.g., student private quarters and squadron-ready facilities).

The microcomputer technology is now available to develop the PET or similar portable training system. The PET would provide many new training capabilities in environments where students, trainees, or instructors must be physically separated or must work together from different locations on a training site or across training sites. The cellular modem system would preclude the need for telephone lines or any other hardwire infrastructure. An artist's conception of the relative size of the PET and desktop training station is illustrated in Figure 3.

4. SUPT Simulation Training Laboratory

The addition of a training laboratory as a new component in the SUPT program would facilitate the integration of academic knowledge taught in the classroom with cockpit procedures and flying skills acquired via flight simulation. Analysis reveals a learning pattern in which students learn to correctly verbalize flight procedures but are unable to execute these procedures in the cockpit without considerable trial-error experience. Like the aircraft, full-fidelity flight

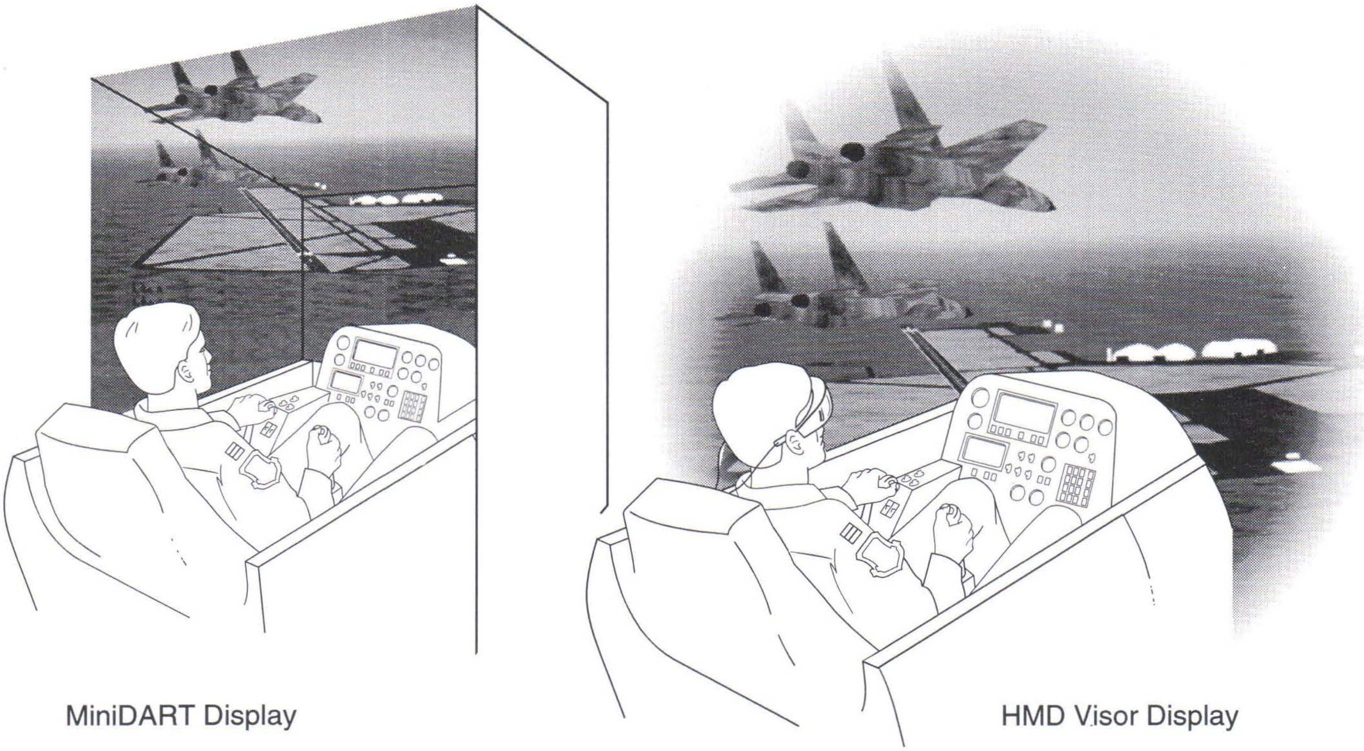

Figure 2. Artist's conception of two flight simulators.

simulators are too complex to practically accommodate initial introduction, familiarization, and practice on basic aircraft control skills and navigation procedures. The training laboratory would provide intermediate fidelity simulators or "part-task trainers" for building hands-on skills prior to high-fidelity flight simulator training and aircraft training phases. Additionally, the simulation training laboratory would provide an environment that is conducive to team training, whereby students, in groups of two or three, generate greater learning synergy and mutual support. Figure 4 shows an artist's conception of two selective part-task trainers, one for practicing basic aircraft control skills on the left and the other for practicing navigation procedures on the right.

5. Instructional Simulations

More powerful microprocessors have enabled the development of real-time simulations that provide both dynamic conditions of actual flight and the type of instructional guidance used in the most effective interactive CAI. Instructional simulations elevate the level of interactivity by challenging students to perform continuous perceptual and decision-making tasks that are similar to those encountered during actual flight. Automated performance assessment keeps students moving toward higher levels of speed and accuracy, and visual or acoustic feedback is provided in various formats to guide individual learning. Instructional simulations can be used to build mental proficiencies for many flying tasks prior to advanced training in a full-fidelity environment. The following are a few of the training areas which would be targeted for this technology as precursors to flying training: (1) instrument interpretation and radial geometry concepts and problem solving; (2) position interpretation/ orientation; (3) fix-to-fix navigation practice; (4) tasks involving on-line voice simulation of tower communications; (5) overhead landing pattern principles and procedures; (6) formation flight concepts and principles; and (7) low altitude flight strategies. Like most of these proposed technologies, instructional simulations are not restricted to aviation training. Such simulations can be designed to teach and enable students to become highly proficient at any task that requires accurate responses to dynamic information and rapid decision-making skills. Such skills are prevalent within many real-world vocations, from trading on the stock market floor to monitoring and operating high-speed machinery.

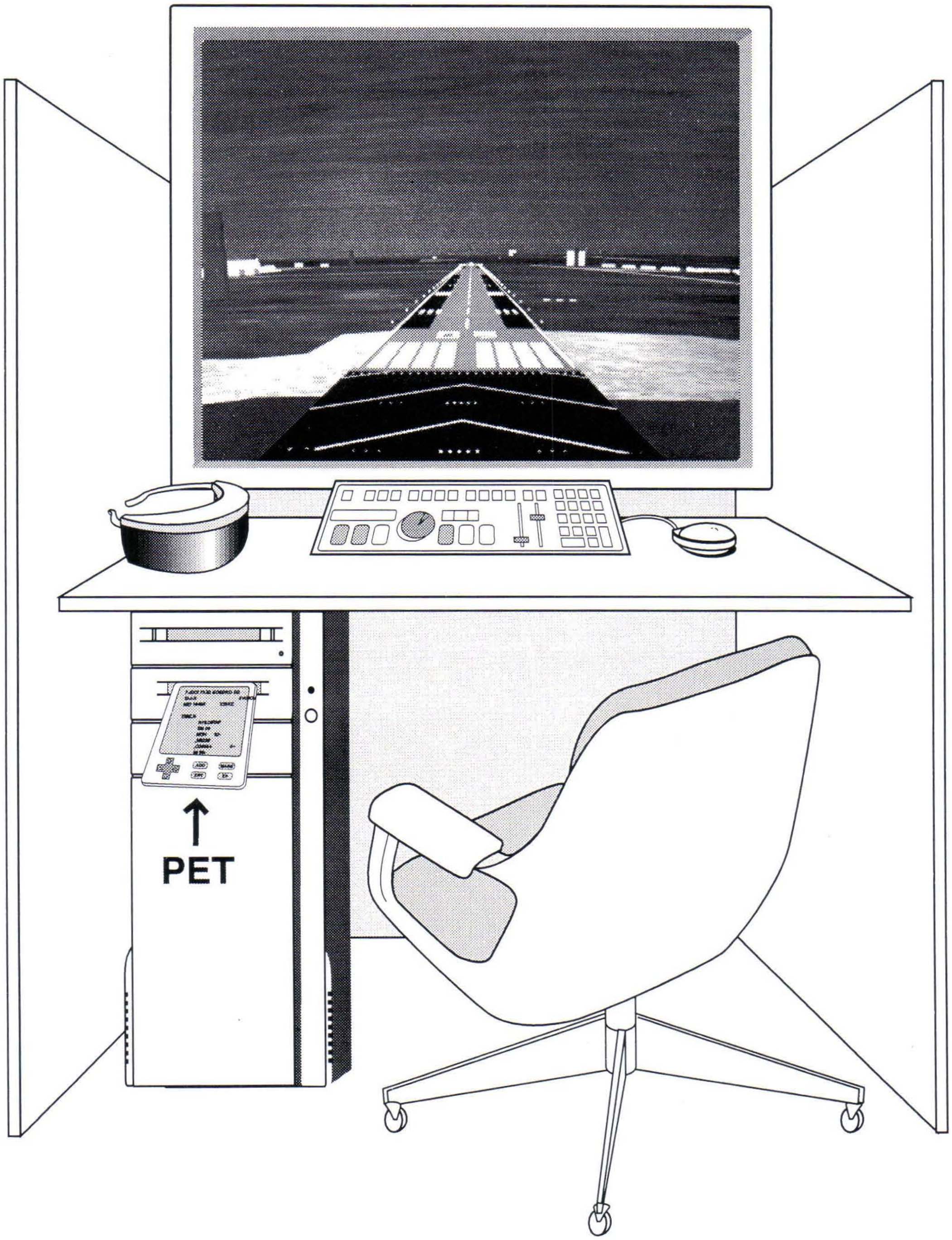

Figure 3. Artist's conception of relative size of PET and desktop training station.

6. Unit Training Device (UTD)

This training device will provide a fully-equipped and functional replica of the training aircraft cockpit at a much reduced cost, compared to previous flight simulator designs. The UTD would offset current simulation training deficits by providing greater visual-display and training-guidance capabilities. Also, the UTD would be a stand-alone training device which

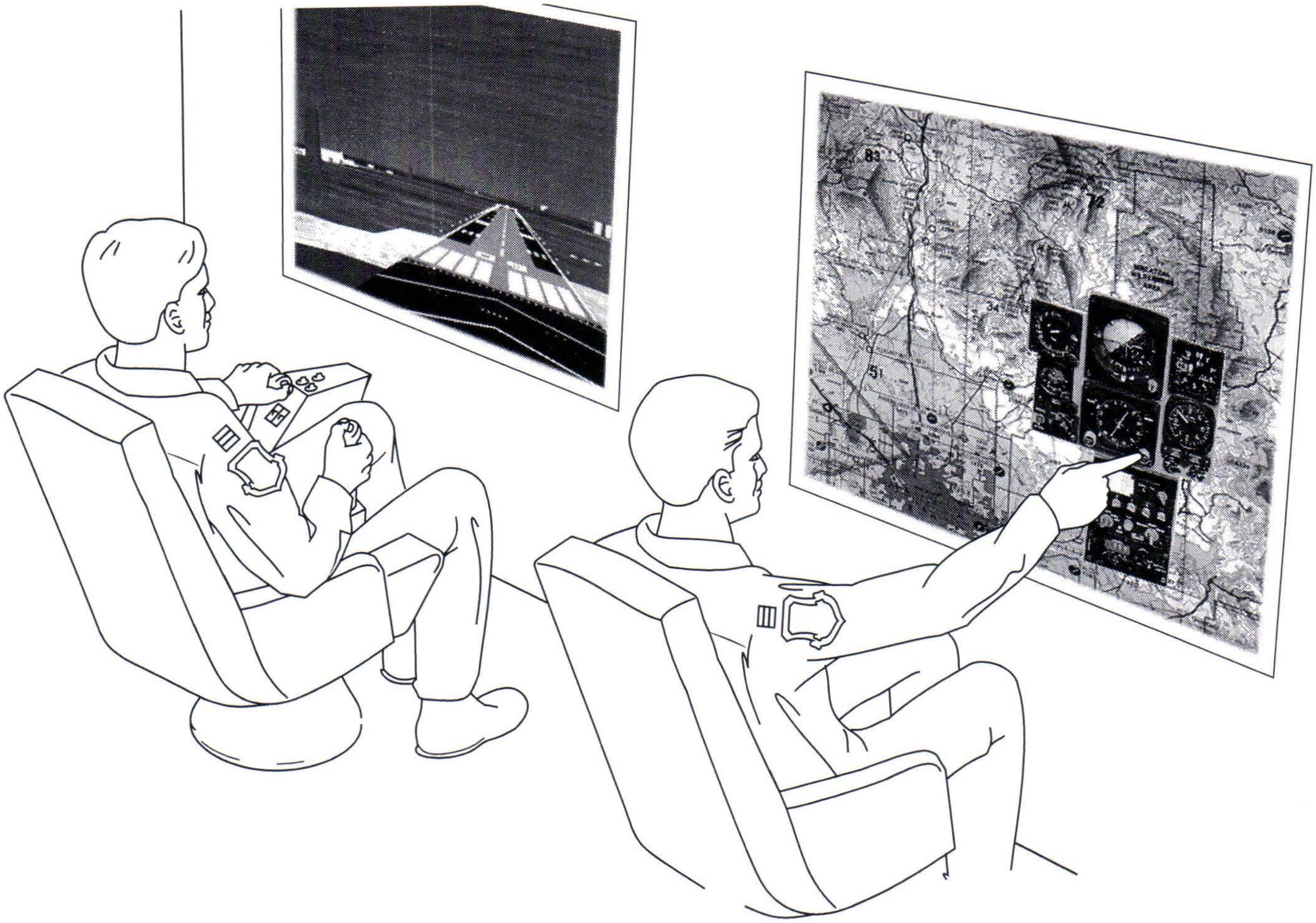

Figure 4. Artist's conception of two selective part-task trainers.

would not require the assistance of IPs and simulator operators for students to practice flight maneuvers on their own or in student teams. Students would be able to fly full training missions in the UTD and receive automated pre-briefs (prior to each flight) and debriefs (after each flight). Prebriefs are normally conducted by an IP to provide students with initial weather, flight conditions, and mission information prior to each training sortie in the aircraft. Debriefs are also conducted by IPs and consist of feedback on the student's performance in the aircraft and recommendations for improvement. It is expected that these new capabilities will provide for greater transfer of flying skill from simulator practice to the aircraft. The UTD would be compact, easily transportable, and would operate in standard facilities without augmented power or cooling provisions. This type of flight simulator combined with DART or HMD technology constitutes a powerful yet low cost simulation package (Boyle & Edwards, 1992).

7. Simulation Networking

Simulator networks, using distributed interactive simulation (DIS) technology, would link two to four flight simulators together, from any combination of training bases in the U. S., so student pilots could practice formation and other joint flying activities. Such a network enables two or more pilots at different training locations to occupy the same virtual (simulated) airspace at the same time. That is, they can see each other's aircraft, communicate via radio, and maneuver together in the same way as in actual joint flying activities. Multi-ship simulation would provide

highly capable flight environments for instructor-student or "lead-wingman" pairs or four-ship missions.

Specific types of SUPT training supportable via network flight simulation include the following: (1) formation flight: "fingertip" aircraft control skills and closure rate estimation and control; (2) estimation and control of aspect angle and heading crossing angle for co-altitude rejoins (breaking away from close formation, then forming up in close formation again); (3) overhead landing pattern scenarios with multiple aircraft, emergency aircraft recovery and related drills and problem solving; and (4) multi-ship training mission rehearsal (simulator practice prior to an aircraft sortie). Training simulation networking can also be applied to a number of training tasks that require more than one person working together to monitor and control complex systems that are distributed across remote locations. These would include management of shipping services (e.g., ground, sea, or air transport), operation of communications systems, and the maintenance of travel services, to name only a few.

8. Portable Electronic Trainer (PET) in the Cockpit

Ever since flight instructors began training students, they have faced the challenge of recording information on the student's in-flight performance. IPs have traditionally used notebook-style checklists and rating forms on a "kneeboard"—a small notebook that is strapped around the pilot's leg during the flight. Kneeboards have drawbacks as training aids because (a) there is little space for written information; (b) the IP must look down to write and may miss important student behavior; (c) notes must be manually transferred to some type of filing or storage system for use beyond the immediate debrief; and (d) using kneeboards during night sorties is awkward. All of these drawbacks could be corrected by modernizing the kneeboard concept. The PET could conceivably be equipped with a special set of functions that would enable instructors and student pilots to enter relevant flight data via a simplified keyboard or touchscreen interface with minimal distraction during flight. A color LCD (about 5" x 5") would display a simple menu that could be illuminated during night flights. Student performance notations and ratings could be made with a few keystrokes or screen touches. The resulting PET data would interface directly with the Aeronautical Training Recorder (ATR, described below) to integrate performance ratings and notes with respective flight events. All such data could be immediately downloaded to the SUPT hub computer after the flight to update the student's proficiency profile and to use for debriefing. Whether the device is used on the knee or attached to a panel in the cockpit, it would be easily attached and removed and designed to comply with flight safety regulations.

The PET could also be used by IPs during flight simulator training for the same performance-monitoring purposes. Increasing the quality and quantity of useful performance data available to IPs during debrief was emphasized as a main concern of instructor pilots. IPs must work with a number of students, and they are currently unable to remember and/or write down enough information to optimize student guidance during flying training. IPs would use the PET to access and review a student's proficiency profile which would contain previous flying experience and performance ratings on each required maneuver. This would extend its usefulness to all phases of training, from academics to flight training in the aircraft. PETs would also help keep individual students on track by keeping them informed of their flying progress and immediate performance objectives. Generally speaking, the PET could be used in a variety of field-training situations where instructors must focus most of their attention on safety and supervisory functions. Performance data could then be easily downloaded to other systems or analyzed and used to provide feedback to the student during field training.

9. Aeronautical Training Recorder (ATR)

The Aeronautical Training Recorder would capture a continuous sequence of real-time, dynamic flight data from the aircraft during training sorties. Aircraft position data (longitude, latitude, and altitude) would be combined with instrument data (airspeed, fuel, g-force, etc.) and sampled at about 60 Hz, recorded in a digital format, then integrated with a local terrain database to re-create actual training flights on ground-based simulation systems. This capability should vastly improve debriefing by providing the IP with a complete replay capability of all flight events that could be reviewed and discussed with the student after training sorties in the aircraft.

The ATR would consist of three major components: (a) an aircraft-mounted (on-board) microcomputer with high-capacity data storage; (b) an on-board Global Positioning System (GPS) linked to the ATR computer; and (c) a ground-based computer system that would combine aircraft flight data (instrumentation and GPS) with a local terrain database. The recording process could be manually engaged and disengaged at any time during the flight by the instructor using the PET as the in-flight ATR interface.

A ground-based image generator would reproduce any recorded portion of the flight and afford students and IPs a variety of viewpoints when reviewing flight events (tower view, inside-cockpit view, off-the-wing view, and stern view). The ATR would remove the IP's

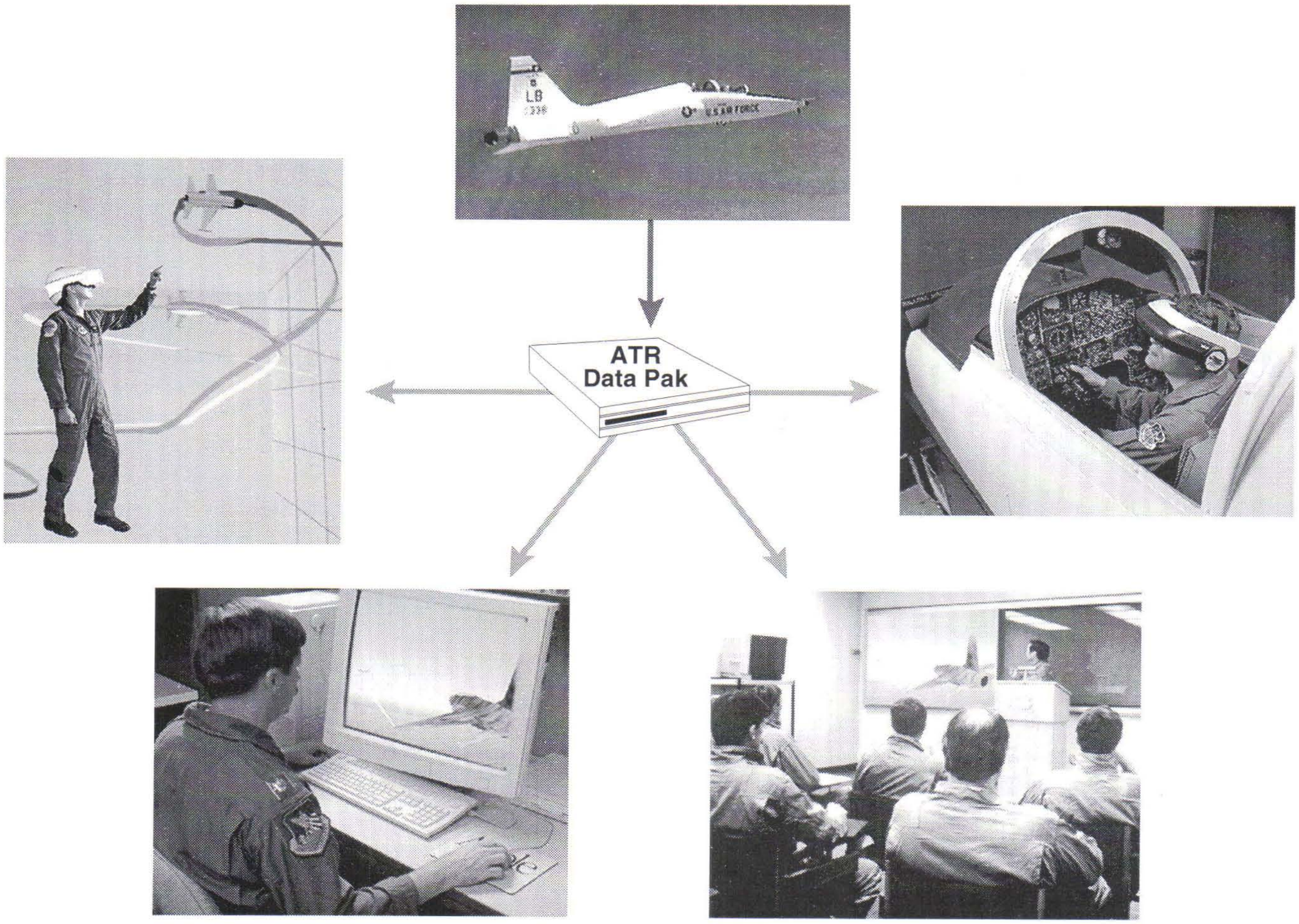

Figure 5. Artist's conception of integration of in-flight training with ground-based training.

challenge for remembering dynamic details about each training sortie. Student pilots could be debriefed in a passive (view only) format, or the ATR data pack could be plugged into the UTD flight simulator to enable a student to re-experience a sortie in the cockpit or re-fly maneuvers that were found to be most difficult in the UTD simulator. Figure 5 shows an artist's conception of the way in which the ATR system would closely integrate in-flight training with ground-based training and practice activities.

10. Instructor/Student Associate

Expert systems technology has potential for SUPT applications. It may be possible to develop an Instructor/Student Associate (ISA) to aid students as they learn to fly in the UTD or even in the training aircraft. Prompting and instructional feedback logic within the system would be based upon pilot expertise (knowledge base), instructional principles, and real-time comparisons between the student's performance and established performance criteria. However, the instructor would be able to override the ISA as needed.

In a fully automated mode, the ISA would provide aural cues or advice on how to correct an error when a student pilot meets or exceeds allowable parameters during a maneuver. In a manual mode, the IP or student could query the ISA for advice on a particular maneuver that has just been completed or is about to be attempted. The ISA would be a voice-activated system to provide for minimal pilot distraction and would use student proficiency profiles to adjust advice based on individual ability and level of skill. Systems like the ISA could be used to enhance the guidance

capabilities and independent training functions of any simulation-based training system.

Instructor Pilot Feedback on Study Analysis and Results

IPs who participated in the original interviews were briefed on the research teams findings. Using a four-point Likert-type rating scale, the IPs rated each of the six identified training problem areas on its "degree of seriousness" in terms of impact on SUPT training. They also rated each of the proposed technologies on the degree that it would help overcome each training challenge. Instructions on the questionnaire were as follows: *"Please rate each of the six problem areas below in terms of its degree of seriousness in affecting SUPT trainee performance and ability to successfully complete training. (0 = unsure, 1 = not serious, 2 = somewhat serious, 3 = very serious)."* Mean ratings are listed in order of magnitude:

Position interpretation	2.8
Overhead landing pattern	2.6
Formation flight	2.6
Fix-to-fix navigation	2.3
Instructor continuation training	2.2
Low altitude flight	2.0

Instructions for rating probable effectiveness of the proposed M&S solutions questionnaire were as follows: *"Please rate each of the modeling/simulation solutions in terms how effective/useful you think it would be for solving SUPT problems experienced by students and IPs. (0 = unsure of usefulness, 1 = not useful, 2 = useful, 3 = very useful)."* Mean ratings are listed in order of magnitude:

Aeronautical Training Recorder	3.0
Video (recording out-of-cockpit views)	2.8
Instructional simulation	2.8
DART	2.8
Large visual displays	2.6
3-D Displays	2.6
Unit Training Device	2.6
Upgrades in CAI	2.4
Simulation networking	2.1
PET in the cockpit	2.0

(The names of some of the technologies used in the questionnaire varied slightly from those in this article. The SUPT hub computer, simulation training lab, and instructor/student associate were not included in the questionnaire.)

These results generally indicate that instructor pilots concurred with the challenges and technology-based solutions identified by the laboratory investigators. IPs rated all of the identified training problem areas as serious to very serious in SUPT. All of the proposed technology solutions were rated as useful to very useful for application to these training challenges.

In conclusion, we believe the modeling and simulation technologies described in this article can improve SUPT in general and the six identified training challenge/problem areas in particular. While these six areas were the ones most often mentioned during the interviews, they were not the only areas of need described by the IPs. It is important to recognize that acquiring these technologies would benefit many, if not all, other areas of the SUPT syllabi. It is also apparent that many of the technologies and methods recommended for pilot training would facilitate education and training in a variety of other settings in schools, colleges, and technical training programs. □

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Modeling and Simulation: A Rationale for Implementing New Training Technologies

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The previous article presented in this special section of this issue, *Potential modeling and simulation contributions to specialized undergraduate pilot training,* (Andrews, Edwards, Mattoon, and Thurman, 1996), described several modeling and simulation (M&S) technologies proposed for increasing the effectiveness of U. S. Air Force Specialized Undergraduate Pilot Training (SUPT) and other applications. The purpose of the present article is to provide support for these training innovations based on theories and empirical findings of training, education, and psychology research and to stimulate creative planning for future technological developments. A more detailed description of pilot training technologies and methods can be found in the technical reports, *Reasons for implementing modeling and simulation technologies in Specialized Undergraduate Pilot Training,* Mattoon (1995), and *Potential modeling and simulation contributions to Air Education Training Command flying training: Specialized Undergraduate Pilot Training,* Andrews *et al.* (1995).

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An Overview

Reductions in the Air Force budget, the advanced age of training aircraft, the increasing need to train pilots to operate sophisticated electronic systems, and significant advances in M&S technology have bolstered the current initiative to modernize pilot training. SUPT consists of three major training components that are separated by time, space, and methodological boundaries: (a) Academics includes lecture-based training with some computer-assisted instruction (CAI) and focuses on facts, concepts, and principles associated with aircraft systems, cockpit procedures, and aeronautical phenomena. (b) Flight simulation training involves hands-on practice for cockpit procedures and takes place at a special facility where flight simulators are permanently housed and maintained. (c) Flying training takes place in the training aircraft where students gain their actual flying experience. The M&S technologies proposed by Andrews *et al.* (1995, 1996) would boost the effectiveness and efficiency of pilot training by modernizing performance measurement systems, by advancing students through training as a function of their individual proficiency, by providing students with individualized skill-building opportunities, and by affording more robust training experiences in the flight simulator. In addition, several issues discussed and technologies proposed for pilot training have implications on software development and the implementation of technology in other areas of education and training.

Support for Proposed M&S Technologies

Some of the current methods used for measuring student pilots' performance are limited for assessing and predicting pilot proficiency. First, multiple-choice tests are used frequently in SUPT academics, and students' knowledge of procedures are assessed by their ability to recite the correct steps in the proper order. However, such recognition and recall tasks alone do not adequately assess learners' ability to apply newly-

acquired knowledge under the stress and time constraints experienced in operational environments (Gopher, Weil, & Siegel, 1989; Phye, 1986; Royer, Cisero, & Carlo, 1993). Second, a four-point rating scale (unsatisfactory, fair, good, and excellent) is used to rate student performance on most flying tasks, but this ordinal measure does not show the magnitude of difference between one student and another or reveal qualitative information about the type of errors made and aspects of individual performance that need improvement.

As noted by Fuller, Waag, and Martin (1979), who analyzed summary score measures for aircraft maneuvers conducted during pilot training, "...a single score will have no diagnostic value. It will not provide information as to which parameter is producing the greatest deviation from the ideal flightpath" (p. 13). Also, instructor pilots (IPs) report that ratings may vary as a function of training schedule instead of reflecting actual pilot ability. For example, a pilot who performs a maneuver very well on the first try may receive a "fair" rating but is likely to receive a "good" or even "excellent" rating for performing the same maneuver at the same level of proficiency on a later training sortie. This is often a judgment call by the IP that reflects the need to regulate student flow through the program rather than to precisely define student performance (Capt. P. Hirneise, personal communication, August 22, 1995).

These and other training challenges are not only present in commercial and military pilot training programs. Many potentially dangerous tasks that are performed under stringent time contingencies, such as heavy equipment operation and management of inflammable and hazardous materials, are difficult to learn in a manner that maximizes skill development while minimizing risk. Further, pilots must learn math and physics principles that involve some of the same time and motion problems encountered in high school and college physics courses. Thus, the intellectual and dynamic performance challenges experienced by pilots share some characteristics with challenges within other disciplines.

Proposed M&S Technologies for SUPT

The general purpose of implementing new M&S technologies is to increase the effectiveness and efficiency of both academics and flying training. Each training technology and method that was proposed for Air Force SUPT by Andrews *et al.* (1995, 1996) is discussed in terms of its potential advantage(s) over technologies and methods currently being used and other training and educational environments.

SUPT Hub Computer System and Student Proficiency Profiles

The proposed SUPT hub computer system would collect and process student performance data in the form of individual student proficiency profiles, adapt training software to meet each student's needs, and distribute CAI and simulation software to training sites throughout the training base. The hub would consist of at least one "super minicomputer," a high-capacity data storage system, and a network infrastructure. Proficiency profiles would maintain performance data such as test scores, error patterns, speed and accuracy on decision-making tasks and cockpit procedures; generate performance summaries that identify individual abilities, strengths, and weaknesses within each knowledge and skill area; adjust the amount and type of instruction according to student progress; and generate recommendations that guide the student's time management and choice of training activities. Student proficiency profiles or individual "portfolios" have been suggested as a more holistic and valid method of judging student ability compared to course grades and scores on standard and mastery-based tests (Gardner, 1991, 1993; Perkins, 1992).

A second major function of the SUPT hub computer system would be to adapt training materials and tasks to suite each student's learning profile and ability. A number of adaptive instructional strategies that function according to changing individual needs have proven successful for teaching typical school course material in mathematics (Ross & Rakow, 1981), science and language concepts (Johansen & Tennyson, 1983; Tennyson, 1981), and cognitive strategies (Breuer & Hajovy, 1987). Adaptive computer-based simulation training has also been devised and tested for teaching the type of complex, dynamic skills employed by pilots. For example, Fabiani, Buckley, Gratton, Coles, Donchin, and Logie (1989), Frederiksen and White (1989), and Mané, Adams, and Donchin (1989) demonstrated several microcomputer-based simulation methods to teach the type of rapid decision making and perceptual and psychomotor skills that pilots use for complex maneuvering and maintaining "situation awareness."

The rationale for adaptive instruction is based on the fact that even students with equal potential may not have the same aptitude for managing their study time and efforts (Snow, 1992). However, due to the fact that U. S. schools and adult training programs require relatively equivalent teaching and time among students (e.g., graduation of intact student groups from one grade to the next), adaptive instruction would require substantial restructuring of current education and training programs. This is because students vary significantly in their ability to learn and progress, and a fully individualized program would lead to a similar amount of variance in student completion times in each

curriculum area. Unfortunately, unlike apprenticeship programs, most schools and training institutions are not willing to give up instructional uniformity, even at the expense of reduced learning effectiveness.

Yet, instructional research indicates that individualized, proficiency-based advancement from elementary to advanced levels of academe would likely increase both efficiency and effectiveness in education and training environments. For example, several components of individualized training have proven to be highly effective (Bloom, 1984). These include one-to-one tutoring, individual reinforcement, immediate performance feedback, facilitative cues and explanations based on each student's error patterns, and proficiency-controlled time on each learning task. Bloom's review of research on these interventions indicates that as many as 98% of students (two standard deviations above the mean) who receive one-to-one tutoring perform better than those who receive group instruction. Each of the other four instructional interventions has been shown to be at least half this effective (one standard deviation or greater) for improving learning and skill development. Although based on school learning environments, these impressive conclusions would likely hold true in adult training programs like SUPT where practice (i.e., direct engagement in criterion tasks) is the most prominent learning intervention.

Similar to most school systems, SUPT students' advancement from beginning academics to graduation from undergraduate pilot training is largely a function of predesignated schedules instead of individual ability to demonstrate proficiency as a knowledgeable and skilled pilot (Andrews *et al.*, 1995, 1996). This "lock-step" training process advances students from one training block (specified portion of the curriculum and performance objectives) to the next as a homogeneous group. There are some options available for remedial training when a student pilot falls behind, but attending to individual needs and abilities is severely hampered by the group-training approach just as it is in public schools.

Some schools partially compensate for individual differences by providing special services to students who have particular study problems (tutoring) and by enrolling "gifted" students in "accelerated" courses. At the adult level, colleges offer a variety of course levels in each subject to accommodate various levels of prerequisite knowledge and skill. However, U. S. learning institutions still closely follow our American heritage in reference to human equality and equivalency in education, so the majority of students must participate and "pass" the same grades and courses regardless of differences in individual ability.

This philosophy of equivalent education is especially apparent in the current SUPT program, which assumes that students who fail any main objective were not "meant" to be pilots. Additionally, those student pilots with exceptional abilities simply move through SUPT training with greater ease, instead of being formally assigned to advanced training or tutoring duties to assist other students. The accommodation of individual differences in SUPT may increase efficiency and effectiveness of training in several ways: (1) students would learn more efficiently with instruction that is tailored to their immediate needs and ability; (2) potentially competent student pilots who experience particular problems during training could quickly overcome them via individual tutoring; (3) exceptional student pilots could be quickly identified by student proficiency profiles; (4) superior abilities could be exploited by assigning exceptional student pilots to tutoring duty; and (5) superior students could be motivated and challenged to excel by receiving official approbation and possibly accelerated promotion.

In the proposed training system, responsibility to control training materials and activities would gradually shift from the SUPT hub to the individual student as s/he masters knowledge and pilot subskills. This approach is based on research which suggests that capable learners may benefit the most from automated instruction that moves from a computer-controlled to a learner-controlled format as they progress in their understanding of the subject matter and their proficiency to study and practice independently (Mattoon, 1994a, b; Steinberg, 1989). As training progresses, student pilots would be encouraged to develop independent decision-making skills, learn how to take advantage of electronic performance-support tools (e.g., proficiency profiles), and learn interdependent student-team strategies for meeting training goals. Such broad-ranging skill development has been observed among students in schools as the result of implementing flexible, interactive computer-based instruction and information processing tools (Chernick, 1990; Newman, 1990) and cooperative learning strategies (Cohen, 1994; Riel, 1990).

The rapid advancement of computer technologies has produced more powerful and capable systems but has been accompanied by a massive increase in the cost of periodic updates of software, hardware, and network infrastructure. To partially compensate for this problem, the SUPT hub and training software is envisioned as a centralized system whereby procurement of new software or reprogramming would be immediately activated throughout the training base via a local area network (LAN). A centralized system would make it easier for SUPT administration to procure a long-term software and hardware contract that could include formative evaluation and maintenance of the entire system. Such a wide-ranging contract has some distinct advantages for institutions that require information or training systems to serve a large population of users (e.g., military, school districts,

universities, and large corporations). A single long-term, wide-ranging contract could fulfill all modernization, formative evaluation, and system maintenance needs. Such a contract would reduce the size of the in-house technical department to a small staff of personnel with training, engineering, and contract management expertise.

Portable Electronic Trainer

The Portable Electronic Trainer (PET) system would be a portable microcomputer, similar to currently available electronic message pads (Lee, 1995), but with some additional capabilities. The PET would enable students and IPs to access student proficiency profiles from any location on the training base and would also "dock" with a desktop training station that would supply additional hardware (e.g., touch-screen display and CD ROM) for full multimedia capability. Remote links from PETs to the SUPT hub and other systems would be accomplished via cellular modem.

The PET system would feature interactive training and performance-support functions that would provide opportunities for students to accelerate their knowledge and skill improvement via dynamic visual demonstrations of complex aviation concepts and procedures and by providing practice via instructional simulations that replicate flight conditions and help students transform their knowledge into operational skills. Each student would monitor his/her own proficiency profile which would continuously update and describe individual progress in each knowledge/skill area. The PET system would also function as the primary delivery system for SUPT academics courses. Course material that consists mostly of text could be delivered by the PET independently in students' quarters, the classroom, or any location within range of the cellular modem. Materials that require larger displays for interactive and simulation-based training would be delivered from any of the PET docking stations throughout the training base.

The PET concept can be extended to education and training institutions that need a portable instructional delivery system which offers the flexibility of a miniature computer yet does not have the processing and storage limitations associated with most portable computational tools. For example, when operated independently, the PET would be as convenient as a calculator; when docked with a desktop system, the PET would offer full visual and audio display capabilities; and when linked with the SUPT hub (from the docking station or in the field via cellular modem), the PET would provide access to most training material, subject matter databases, and communication with any IP or fellow student.

PETs would also help exploit IPs' expert knowledge and skills. One of the most serious difficulties in implementing one-to-one tutoring is that instructors seldom have enough time to attend to each individual. Instructor pilots are currently tasked with the labor-intensive and repetitive job of delivering the same content material to each new group of students. The PET would increase IPs' availability to individuals by delivering modular content material to each student and thus reduce IP lecture duty to almost zero. This would make IPs more accessible to students in the classroom and for flying training sorties in the aircraft. The LAN system that connects PETs to the SUPT hub would enable students to engage in cooperative learning (e.g., participate in joint interactive simulations and tutor each other on various instrument flight procedures) across remote locations on the training base at any hour of the day or night.

Although SUPT students' main goal is to learn to fly, a very complex and challenging task, they must first learn to perform a substantial number of "subtasks." These subtasks require the development of both intellectual and psychomotor skills or "subskills" (part-task skills), which in turn facilitate mastery of the most complex skill, flying the aircraft. Such complex skills consist of closely integrated units of intellectual, perceptual, and motor components and are characterized by the learner's ability to perform with speed, accuracy, and smooth, effortless action (Gagné, 1962; Schneider, 1985). The PET training system would provide interactive, dynamic practice that assists students develop cognitive subskills that are necessary for decision making in rapidly-changing in-flight environments. Students would practice instrument procedures for navigation, landing, and take-off via instructional simulations delivered by the PET.

Instructional simulations can be designed to teach many types of dynamic skills (Alessi, 1988; Breuer & Hajovy, 1987; Reigeluth & Schwartz, 1989), including pilot skills (Gray & Edwards, 1991; Mané, Adams, & Donchin, 1989). Unlike print-based instruction or conventional CAI, instructional simulations graphically reproduce dynamic systems by replicating functions, changing conditions, and varying system states (Mattoon & Thurman, 1990). Instructional simulations can replicate flight conditions that are normally displayed on cockpit instruments (e.g., air speed, altitude, radar, and other navigation aids) to enable students to gain speed and accuracy in responding to a variety of situations. Instructional simulations help students construct useful mental models of aircraft (Waag, 1986) and many other types of complex systems and environments (Mayer, 1989; Mayer & Sims, 1994; Munro & Towne, 1992; Perkins & Unger, 1994). With the fast advancement of graphic displays and powerful microcomputers, instructional simulations are becoming a powerful and important alternative to lecture, conventional CAI, and other forms of training that are less interactive and limited to teaching declarative knowledge.

Unit Training Device

The Unit Training Device (UTD) is envisioned as a high-fidelity flight simulator that would make it possible for students to effectively practice virtually all flying procedures and maneuvers on the ground prior to training in the aircraft. Flight simulators accurately replicate physical and functional aspects of the aircraft and some of the most salient aspects of actual flight (Hays & Singer, 1989). The flight simulator that is currently used in SUPT, the Operational Flight Trainer (OFT), adequately replicates the physical components of the training aircraft and many of the instrument functions, but it does not simulate visual imagery that is essential for effective practice on key flying tasks like landings and formation maneuvers (Andrews *et al.*, 1995). Also, students need assistance from IPs and simulation operators to practice in the OFT. These limitations may contribute to the student's development of an inaccurate, or at least, incomplete mental model of the flight environment.

Wilson and Rutherford (1989) described a mental model as "...a representation formed by a user of a system and/or task, based on previous experience as well as current observation, which provides most (if not all) of their subsequent system understanding and consequently dictates the level of task performance" (p. 619). The OFT's lack of a complete visual system makes it difficult for student pilots to develop a robust mental model of the flight environment prior to training in the aircraft, and the additional personnel needed to operate the OFT limit students' training time and increases maintenance costs. Implementation of the UTD would address these problems.

Emerging flight simulation technology has expanded ground-based training to include a wider variety of single and multiship mission training (Boyle & Edwards, 1992; Mowafy & Thurman, 1993; Thomas & Geltmacher, 1993). The UTD would enhance simulator training by providing a wide-field-of-view, high-resolution visual system and an automated training guidance system that adapts training scenarios to each individual according to his/her proficiency profile. The UTD would also surpass the OFT in flexibility due to its small size, portability, and capability to be operated by the student without the assistance of an IP or simulator operator. The UTD would also be portable so that it could be moved about to various strategic locations throughout the training base.

UTDs would offer two major training advantages for multiship training: (a) simulator networking so that two students could practice formation maneuvers, and (b) capability to visually simulate a lead or wingman aircraft so that the student pilot could practice joint maneuvers without the assistance of an IP or another student. A UTD voice-recognition and voice-generation system would enable the student to alter flight conditions during training scenarios or receive voice guidance from the computer, just as IPs provide assistance to students in the aircraft during training sorties.

Real-time performance feedback would be made possible by an automated performance-assessment subsystem that would track student actions and simulator responses. Although Brecke and Miller (1991) and Waag, Raspotnik, and Leeds (1992) identified major challenges to measuring pilot performance, the most serious roadblocks are associated with the complexities of combat engagements. In contrast, the skills associated with beginning pilot training are less complex and better defined in quantitative terms within SUPT course syllabi. In fact, much older prototype systems have demonstrated that automated performance measurement techniques work fairly well on basic aircraft maneuvers (Fuller *et al.*, 1979), but at the time this research took place, the size and expense associated with such systems was prohibitive.

Many of these problems have been alleviated by reduced costs of computers and faster computational systems. Of course, flight simulation is a specialized area of training that bears little resemblance to most training environments. However, the advanced visual system planned for the UTD may also be applied to the simulation of many types of complex systems. For example, the simulation of heavy equipment and vehicles for training operators could substantially improve safety conditions, and the visual requirements of such simulators would be more easily attained because they move slower and do not require the faster display processing rate of flight simulators. Additionally, considering the cost of machinery maintenance, fuel, insurance, and instructor time, heavy equipment operator training may be more cost effective via simulation.

Specialized Visual and Acoustic Displays

The use of two-dimensional and three-dimensional (3D) visual and acoustic information to facilitate learning in mathematics, science, and other disciplines has shown great promise (Glenberg & Langston, 1992; Park & Hopkins, 1993; Perkins & Unger, 1994; Rittschof, Stock, Kulhavy, Verdi, & Doran, 1994; Sein *et al.*, 1993; White, 1993; Winn & Bricken, 1992). However, a review of potential strategies for implementing such displays in education and training programs is beyond the scope of this article. Instead, short descriptions of several types of displays are provided to indicate how this technology area may improve pilot training.

Pilots depend on visual perceptual and sometimes acoustic cues for many flying tasks. Repeated exposure to visual information during actual or simulated flight enables pilots to develop effective mental models that

help them make rapid decisions and solve in-flight problems. Mental models appear to be frequently based on and retained by visual stimuli (Paivio, 1979; Paivio & Linde, 1982; Rouse & Morris, 1986). Generally speaking, visual information used for instructional purposes has proven to facilitate learners' understanding and development of complex concepts far beyond that which can be accomplished with only verbal descriptions (Glenberg, & Langston, 1992; Mayer, 1989; Perkins & Unger,1994). The need for facilitating mental model development will be addressed in the proposed SUPT system by specialized state-of-the-art displays. In the academics phase, specialized displays represent the key change factor in moving from non-interactive, static, print-based instruction to interactive, dynamic, and experience-intensive learning environments. In the SUPT simulator training phase, high-fidelity displays will broaden the scope and increase the effectiveness of skill development in flight-simulation environments.

A multiple rear-screen projection system called the Display for Advanced Research and Training (DART) was developed at AL/HRA and is a likely candidate for the UTD visual system. The DART consists of several CRT projectors that are linked to a multi-channel visual image generator which synchronizes their output to produce one large complete scene. The result is similar to that of a video wall except that screens wrap around the simulator cockpit to give the pilot the same type of view available during flight. A head-tracking system monitors the pilot's line of sight and conveys this information to a computer that drives the image generator. The head-position data is used to switch off projector channels (and the corresponding imagery) that are outside of the pilot's current view to reduce the number of active channels required for producing an acceptable field of view. This "channel-intensive" strategy minimizes the required number of visual channels to reduce overall cost of the system. Compared to other simulator visual systems, DART's commercially available components cut development costs by at least 75% (Thomas & Geltmacher, 1993). The Mini-DART system, also developed at AL/HRA, employs the same technology but further reduces the display size and cost by using fewer screens, projectors, and image channels. Compared to the DART, the Mini-DART is smaller, less expensive, and portable, so it will be the more likely choice for future SUPT and other simulation applications.

During certain maneuvers, pilots use fine visual details to estimate distance and closure rates. For example, they focus on particular parts of their wingman's aircraft to maintain precise positions during formation flights, and when flying at low altitudes, pilots use textures and density associated with ground terrain (Toldy & Miller, 1985). The current OFTs can produce neither visual detail nor a large field of view, so effective practice on formation maneuvers and low altitude flight is not possible. However, planned improvements in image resolution of the Mini-DART would enable student pilots to use flight simulator practice to hone their skills on virtually any flying maneuver. This capability, combined with reduced costs associated with off-the-shelf display components and increased portability of light-weight hardware, makes the DART a good choice for future simulation training applications.

Head-mounted displays (HMDs) consist of some form of head-mounted gear (e.g., helmet or visor arrangement) that projects a visual image to each eye to produce stereoscopic 3D visual perception of simulated imagery. A variety of volumetric cues such as perspective, stereopsis, occlusion, and motion parallax can be incorporated in simulations delivered on the HMD (Ellis, Kaiser, & Grunwald, 1993). The HMD completely surrounds and "immerses" the viewer within the imagery. This produces a convincing illusion of physically residing inside of the visual space and is referred to as virtual reality (VR) (Helsel & Roth, 1991; Rheingold, 1991). Low-cost VR systems are now being designed that have much education and training potential (Mattoon, 1994a, b; Thurman & Mattoon, 1994).

The lack of well-developed 3D mental models sometimes causes student pilots to misjudge closure rates between aircraft and make inaccurate estimates of appropriate flight paths for complex maneuvers (Capt. P. Hirneise, personal communication, April 25, 1995). Thus, training simulations should enable student pilots to incorporate 3D components into their mental models of the flight environment. This suggests HMDs are superior to flat-screen display systems, which have less capability for simulating 3D, take up far more space, and are less portable than HMDs. Yet, HMDs currently lack the visual resolution and wide field of view of the DART. Also, there are still some visual distortion and disorientation problems with HMDs that can affect performance in virtual environments (Grunwald, 1993; Roscoe, 1993). However, it is expected that many of these limitations will soon be overcome and may make the HMD the visual display of choice for simulation systems of the future (Mr. M. Thomas, personal communication, December 14, 1994).

Acoustic displays, although less important than visual systems in most applications, can provide additional sensory information to facilitate learning and performance under high task-load conditions (Sorkin, Wightman, & Kistler, 1989; Wenzel, 1991). Three-dimensional acoustic systems are now available for simulation training. 3D acoustics (i.e., localized sound) is a fairly new advancement in sound-based interface that enables the listener to estimate the direction and position of sound sources within a virtual environment via standard stereo headphones (Wenzel, 1991).

Interactive 3D sound can be combined with 3D visual displays and generated in real-time simulations to provide learners with multi-sensory information about complex systems and phenomena.

Three-dimensional acoustics can be integrated with flight simulation to add perceptual information (e.g., radar warning signals, acceleration of jet engine, wind and weather noises, and specialized auditory tracking cues). Localized sound appears to be one of the most appropriate methods for preventing visual overload within complex electronic environments and may effectively supplement visual cues (Begault, 1993; Begault & Wenzel, 1992). For example, 3D acoustic cues that designate up, down, left, and right relative to the body midline could be used to help SUPT student pilots overcome spatial disorientation during complex aerobatics in the aircraft or the flight simulator (Dr. D. Andrews, personal communication, September 14, 1994). These training and performance-support methods have not yet been tested, but research on augmenting several types of flying tasks via 3D acoustics has just begun and will probably show greater potential in the near future (McKinley, Erickson, & D'Angelo, 1994).

Aeronautical Training Recorder

Structured interviews with IPs indicated that their most challenging task is conducting effective and safe flying sorties (Andrews *et al.*, 1995). Currently, SUPT IPs must continuously accomplish a number of tasks during flying sorties with students: (a) take over controls if a dangerous situation arises; (b) visual cross-checking instruments; (c) assess the student's behavior and ability to control the aircraft; and (d) memorize or write down information about the student's performance. IPs indicate that debriefing (discussing student performance on the ground after a flight) is one of the most important training interventions in SUPT, but the mental workload of the cockpit makes it almost impossible to recall enough information to maximize the potential benefits of debriefing.

Instructor pilots currently use a "kneeboard" during aircraft sorties—a small notebook of forms and note pages that is strapped to the pilot's leg and used to rate student performance, access flight regulations, and write notes. Writing in longhand or even using a concise coding on the kneeboard requires the removal of the instructor's visual attention from the flight situation, and at least one hand (usually two) is occupied during note-taking tasks. This can become a potentially hazardous situation when considering how little flying skills student pilots possess at early stages of training in the aircraft. Also, performance data in a physical (rather than electronic) form must be entered into student records via a computer terminal, so it involves additional time and effort, and increases the likelihood of data-entry errors. These problems could be addressed by an automated flight recording system.

The Aeronautical Training Recorder (ATR) would enable IPs to record actual training sorties, reproduce them in a simulated format, and use the simulations to focus one-to-one tutoring. The ATR would consist of several hardware/software components that are described by Andrews *et al.* (1995, 1996). It would record aircraft position, movement, speed, altitude, and several other types of dynamic data during a training sortie, so specific maneuvers or instrument procedures performed by the student could be "played back" on ground-based simulation systems. A removable data pack would enable the IP to easily transport flight data from the aircraft to ground-based systems where the simulation could be generated. During the flight, the ATR would accept voice commands to control various flight-recording functions: start/stop, purge specified events from the data pack, place electronic markers at specified points on recorded events, and organize voice notes around particular events. This capability would enable the IP to rate each student maneuver and instrument task and mark portions of the flight that need to be discussed or visually analyzed during the debrief. This capability would improve flight safety, because IPs could perform most in-flight training tasks without reallocating their attention or moving their hands from aircraft controls. On the ground, the IP could demonstrate performance problems that occurred during flight on the PET or UTD display systems from any viewpoint inside or outside the aircraft (e.g., tower, plan view, or view from tail or wing). Additionally, by initializing the UTD with the ATR data, any flight procedure or maneuver could be immediately practiced by the student in the flight simulator.

Although the ATR would be designed specifically for pilot and aircrew training, similar devices could be developed to record and reproduce dynamic situations in any potentially dangerous environment or where participants are too occupied to operate video cameras or other recording systems. Additionally, unlike video recordings, the duplication of experiences and situations via simulation are flexible in that conditions and even the entire environment can be changed to suit the needs of the application. For example, actual problematic situations at a robot control station within a manufacturing plant could be digitally recorded in a similar manner that cockpit instrument data is recorded by the ATR. From this data, prototype visual and acoustic simulations could be generated that show how the operator handles each problem. Correct and incorrect procedures and their subsequent results could be simulated without recording additional situations. Trainees or robot designers could view each situation from any viewpoint within the work area to gain insights on the operator interface and potential problems. Also, adding controls to the system would

enable trainees to practice problem-solving operations in real time. The best video systems provide exactly what is recorded from the viewpoint of the camera(s) and cannot be used to generate new or unique situations in real time.

For audio-visual demonstrations of the M&S technologies and concepts discussed in this article, see *The application of modeling and simulation technologies to Air Force Specialized Undergraduate Pilot Training* [video], Mattoon & Gagel (1995).

Conclusions

All of the methods and systems described in this article are within the current technological capability of the U. S. Air Force, and many prototype designs have already been produced by Armstrong Laboratory. Implementation of the proposed M&S technologies and associated training methods would make the academics phase of SUPT a more experience-intensive process by increasing student opportunities to build subskills while acquiring knowledge. Additionally, improvements in training and visual fidelity components of flight simulators and performance-tracking technology in the aircraft would afford more focused instructional interactions among students and IPs during flying training.

The proposed technologies and methods are not restricted to military aviation training. Many training innovations produced for the Air Force have been adopted by commercial airlines, private aviation schools, and education and training in general. In addition, portable training systems like the PET and visual display devices like the HMD have broad-ranging potential for training and operational applications outside of the field of aviation (Mattoon, 1994).

Overall, it is expected that the long-range benefits of new M&S technologies will outweigh short-range costs of development in terms of accelerated knowledge and skill development, more effective use of students' and instructors' time, more robust assessments of individual student ability and potential, safer and more effective training, and greater efficiency per training cycle. □

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